SURFACE PROCESSOR

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Abstract

PURPOSE:To simplify the structure of a surface processor and generate its plasma at a low pressure and reduce its energy for projecting ions on a substrate to be processed.
CONSTITUTION:In a surface processor, a vacuum container 1, an evacuation mechanism 7, a gas introducing mechanism, a cylindrical discharging electrode 2, electrode supply mechanisms 10, 11, 12 for supplying power to the discharging electrode 2, a magnetic circuit 4, and at least one substrate holding mechanism 5 are provided respectively. The magnetic circuit 4 comprises a plurality of annular permanent magnets 401, 402 which are arranged at spaces coaxially with the discharging electrode 2. Further, the respective annular permanent magnets 401, 402 are so magnetized radially that the polarities of their adjacent magnetic poles are opposite to each other. At least two adjacent annular permanent magnets to each other 402 are provided in the periphery of the discharging electrode 2, and the other permanent magnets 401, 401 are provided respectively in the peripheries of the front spaces of the substrate holding mechanisms 5, 5, and further, in the vicinities of the end parts of the magnetic circuit 4, the substrate-mounted surfaces of the substrate holding mechanisms 5, 5 are provided perpendicularly to the center axis of the discharging electrode 2.

[Title of Document] SPECIFICATION

[Title of the Invention] SURFACE PROCESSOR

[Scope of Claim for a Patent]

1. A surface processor comprising: a vacuum container; an evacuating mechanism for evacuating the vacuum container into a decompressed state; a gas introducing mechanism for introducing gas for electric discharge into the vacuum container; a tube-shaped discharging electrode for letting the gas discharge electricity and thereby generating plasma; an electrode supply mechanism for supplying the discharging electrode with electric power for the plasma generation; a magnetic circuit placed around the discharging electrode; and at least one substrate holding mechanism placed inside the vacuum container, wherein:

the magnetic circuit includes a plurality of ring-shaped permanent magnets which are arranged at intervals coaxially with the discharging electrode, the ring-shaped permanent magnets being magnetized radially so that the polarities of their adjacent magnetic poles will be opposite to each other, and

at least adjacent two of the ring-shaped permanent magnets are placed to surround the discharging electrode and the other of the permanent magnets are placed to surround a front space of the substrate holding mechanism, and

a surface of the substrate holding mechanism on which a substrate to be processed is mounted is placed nearby an end of the magnetic circuit so as to be perpendicular to the central axis of the discharging electrode.

2. The surface processor according to claim 1, wherein the discharging electrode is provided as part of a peripheral

surface part of the vacuum container maintaining vacuum sealing by an insulator placed between the discharging electrode and other part of the vacuum container.

3. The surface processor according to claim 1, wherein the discharging electrode is formed in a tube-like shape whose both ends are open and is placed inside the vacuum container coaxially with the vacuum container leaving a gap between the discharging electrode and a peripheral surface part of the vacuum container.

4. The surface processor according to claim 3, wherein:

a tube-shaped electrode surrounding the discharging electrode is coaxially placed between the vacuum container and the discharging electrode, and

the axial length of the tube-shaped electrode is set longer than that of the discharging electrode, and

the tube-shaped electrode is held in floating potential, and

each ring-shaped permanent magnet of the magnetic circuit is placed to surround the tube-shaped electrode.

5. The surface processor according to claim 4, wherein the ring-shaped permanent magnets to be placed at positions corresponding to the circumference of the discharging electrode are placed in a space between the discharging electrode and the tube-shaped electrode.

6. The surface processor according to claim 4 or 5, wherein:

the discharging electrode is formed by a tube-shaped member including two parts having the same axial length and different diameters, and

another magnetic circuit employing two or more ring-shaped permanent magnets are placed around the small-diameter part of the discharging electrode.

7. The surface processor according to claim 6, wherein the discharging electrode is formed in a bellows-like shape having the parts of different diameters alternately arranged in the axial direction.

8. The surface processor according to claim 4 or 5, wherein:

the discharging electrode is formed to have double structure including an inner electrode and an outer electrode, and

a ring-shaped permanent magnet is placed between the inner electrode and the outer electrode.

9. The surface processor according to claim 8, wherein a gap enough for allowing electric discharge is formed between the outer electrode and the tube-shaped electrode.

10. The surface processor according to claim 8 or 9, wherein the ring-shaped permanent magnets provided to corresponding positions on the discharging electrode and the tube-shaped electrode face each other with magnetic poles of the same polarity.

[Detailed Description of the Invention]

[0001]

[Technical Field Pertinent to the Invention]

The present invention relates to a surface processor, and in particular, to a surface processor for processing the surface of a substrate by use of plasma that is generated by DC, RF or microwave electric discharge, which is employed as a dry etching apparatus, plasma CVD apparatus, etc. in manufacturing processes of semiconductor devices.

[0002]

[Prior Art]

As an example of a conventional surface processor, a high-frequency electric discharge reactor which is used for a dry etching process in a semiconductor device manufacturing process will be explained first. In a wiring pattern formation process which is essential for the manufacture of semiconductor devices, the dry etching technique is employed. In the dry etching, mixed gas including halogen-containing gas as its main ingredient is turned into plasma state by means of electric discharge, letting various activated species (atomic hydrogen, atomic fluorine, fluorine-carbon compounds, etc.) caused by the plasma generation react with a thin film on the surface of a substrate, by which parts of the thin film unnecessary for wiring are removed. In the most commonly-used method for turning mixed gas into plasma, two planar electrodes are placed to face each other in a decompressed vacuum container, applying high-frequency electric power to one electrode while maintaining the other electrode at ground potential so that electric discharge will be caused by the energy of the high-frequency electric power, by which plasma is generated between the two electrodes. Such

reactors employing the above method called "parallel planer electric discharge reactors") are used in a variety of fields.

[0003]

As an improved version of the parallel planer electric discharge reactor, magnetron-type electric discharge reactors are well known. In the magnetron-type electric discharge reactor, the efficiency of plasma generation is improved by employing magnetic field generation means which generates a magnetic field in the vacuum container.

[0004]

The construction of a typical conventional parallel planer electric discharge reactor which is employed for a dry etching apparatus will be described briefly referring to Fig. 7. In Fig. 7, a reference number "71" denotes a vacuum container, "72" an electrode for causing electric discharge also serving as a substrate holding mechanism, "73" an electrode which is placed to face the electrode 72 and maintained at the ground potential, "74" a substrate to be processed, "75" an evacuating mechanism for evacuating the vacuum container 71 to a prescribed decompressed state, and "76" a gas inlet pipe for supplying reactive gas to inside the vacuum container 71. An RF power supply 77 and a matching circuit 78 are provided in order to supply high-frequency electric power to the electrode 72. The electrode 72 is provided with an insulator 79 which also serves as vacuum sealer.

[0005]

Fig. 8 shows the construction of a conventional magnetron-type electric discharge reactor which is used as a dry etching apparatus. While various types of dry etching apparatuses employing a magnetic field have been developed so

far, one employing a revolving magnetic field is shown here. In Fig. 8, the same reference characters as those of Fig. 7 designate the same or equivalent elements to those of Fig. 7, namely, the reference number "71" denotes a vacuum container, "72" an electrode also serving as a substrate holding mechanism, "73" a counter electrode, "74" a substrate, "75" an evacuating mechanism, "76" a gas inlet pipe, "77" an RF power supply, "78" a matching circuit, and "79" an insulator. A ring-like electromagnet apparatus 80 having a special magnetic pole arrangement inside is placed so as to surround the vacuum container 71. By the electromagnet apparatus 80 having the special magnetic pole arrangement, a magnetic field vector 81 (magnetic flux B) parallel to the surface of the substrate 74 to be processed can be generated (reference: Journal of Nuclear Materials 200 (1993) pp291-295). Revolving the direction of the magnetic field vector 81 on the surface of the substrate 74 to be processed is also employed widely today.

[0006]

Each of the above two types of electric discharge reactors has been widely used as a dry etching apparatus for etching the surface of substrates to be processed. Each type, delivering enough etching performance in micromachining with a line width of approximately 1 μm, has been employed in numbers of semiconductor factories.

[0007]

[Problem to be solved by the Invention]

However, the conventional dry etching apparatuses which have been explained above involve the following problems or drawbacks.

[0008]

The prime reason why dry etching is used for micromachining in semiconductor device manufacturing processes is that it enables anisotropic etching, that is, etching that gives vertical cross-sectional surfaces. However, in order to obtain a vertical cross-sectional surface by dry etching in microstructure less than 1 μm, ions in the plasma have to be incident on the substrate exactly in the vertical direction. The simplest way to improve the rectilinear motion of the ions is to lower the electric discharge pressure.

[0009]

However, if the electric discharge pressure is reduced too much in the parallel planer electric discharge reactor of Fig. 7, processing speed drops to an insufficient level due to a decrease in the plasma density. Further, the electric discharge itself becomes difficult as the electric discharge pressure is reduced. Therefore, there is a certain lower limit of the electric discharge pressure. Further, the lowering of the electric discharge pressure increases self-bias voltage on the cathode (electrode 74), by which the energy of ions incident on the substrate 74 gets too high and the possibility of damage to the surface of the substrate increases.

[0010]

From the viewpoints of lowering the incident energy of plasma ions and preventing the damage to the substrate surface, the application of the magnetron-type electric discharge reactor of Fig. 8 has also been tested widely. In the magnetron-type electric discharge reactor which generates plasma employing an external magnetic field, the electric discharge pressure can be lowered (1 - 10 mTorr) without increasing the self-bias voltage on the cathode. Consequently,

it becomes possible to reduce ion irradiation energy onto the substrate, and further, the electric discharge at a lower electric discharge pressure is made possible in comparison with the parallel planer electric discharge reactor.

[0010]

However, in the magnetron-type electric discharge reactor, the generated plasma is distributed unevenly depending on the distribution of the generated magnetic field, deteriorating the uniformity of the plasma.

[0011]

It is therefore the primary object of the present invention to provide a surface processor having simple structure, capable of generating plasma at a low pressure, while reducing the ion irradiation energy onto the substrate to be processed.

[0012]

[Means for Solving Problem]

A surface processor in accordance with the present invention comprises: a vacuum container; an evacuating mechanism for evacuating the vacuum container into a decompressed state; a gas introducing mechanism for introducing gas for electric discharge into the vacuum container; a tube-shaped discharging electrode for letting the gas discharge electricity and thereby generating plasma; an electrode supply mechanism for supplying the discharging electrode with electric power for the plasma generation; a magnetic circuit placed around the discharging electrode; and at least one substrate holding mechanism placed inside the vacuum container. The magnetic circuit includes a plurality of ring-shaped permanent magnets which are arranged at intervals coaxially with the discharging electrode. The ring-shaped permanent magnets are

magnetized radially so that the polarities of their adjacent magnetic poles will be opposite to each other. At least adjacent two of the ring-shaped permanent magnets are placed to surround the discharging electrode and the other of the permanent magnets are placed to surround a front space of the substrate holding mechanism. A surface of the substrate holding mechanism on which a substrate to be processed is mounted is placed nearby an end of the magnetic circuit so as to be perpendicular to the central axis of the discharging electrode.

[0013]

Preferably, in the above construction, the discharging electrode is provided as part of a peripheral surface part of the vacuum container maintaining vacuum sealing by an insulator placed between the discharging electrode and other part of the vacuum container.

[0014]

Preferably, in the above construction, the discharging electrode is formed in a tube-like shape whose both ends are open and is placed inside the vacuum container coaxially with the vacuum container leaving a gap between the discharging electrode and a peripheral surface part of the vacuum container.

[0015]

Preferably, in the above construction, a tube-shaped electrode surrounding the discharging electrode is coaxially placed between the vacuum container and the discharging electrode. The axial length of the tube-shaped electrode is set longer than that of the discharging electrode. The tube-shaped electrode is held in floating potential. Each ring-shaped permanent magnet of the magnetic circuit is placed to surround the tube-shaped electrode. Incidentally, instead

of holding the tube-shaped electrode in the floating potential, it is also possible to provide a mechanism for applying bias voltage to the tube-shaped electrode as necessary.

[0016]

Preferably, in the above construction, the ring-shaped permanent magnets to be placed at positions corresponding to the circumference of the discharging electrode are placed in a space between the discharging electrode and the tube-shaped electrode.

[0017]

Preferably, in the above construction, the discharging electrode is formed by a tube-shaped member including two parts having the same axial length and different diameters, and another magnetic circuit employing two or more ring-shaped permanent magnets are placed around the small-diameter part of the discharging electrode.

[0018]

Preferably, in the above construction, the discharging electrode is formed in a bellows-like shape having the parts of different diameters alternately arranged in the axial direction.

[0019]

Preferably, in the above construction, the discharging electrode is formed to have double structure including an inner electrode and an outer electrode, and a ring-shaped permanent magnet is placed between the inner electrode and the outer electrode.

[0020]

Preferably, in the above construction, a gap enough for allowing electric discharge is formed between the outer

electrode and the tube-shaped electrode.

[0021]

Preferably, in the above construction, the ring-shaped permanent magnets provided to corresponding positions on the discharging electrode and the tube-shaped electrode are placed to face each other with magnetic poles of the same polarity.

[0022]

[Action]

The present invention has been made to propose a surface processor capable of generating high-density plasma of excellent uniformity at a low pressure. In the present invention, magnetic field that has been used in conventional surface processors for plasma confinement is also used for generating the plasma, by which highly uniform high-density plasma can be generated with ease. As a mechanism for utilizing magnetic lines of force (magnetic field lines) simultaneously for both the plasma generation and the plasma confinement, the use of a high-frequency electric discharge mechanism is desirable.

[0023]

In the surface processor according to the present invention, the electrode for supplying high-frequency electric power for causing the electric discharge for plasma generation is changed from the conventional planar electrode into a tube-shaped electrode, and ring-shaped permanent magnets are placed to surround the discharging electrode. By the construction, plasma is generated inside the tube-shaped discharging electrode and diffuses in the inner space of the vacuum container. Further, the density of the plasma is increased in comparison with plasma in conventional surface

processors by the magnetic field generated by the ring-shaped permanent magnets. The high-density plasma diffusing inside the vacuum container is then confined with high uniformity in a space in the vacuum container by a magnetic field generated by ring-shaped permanent magnets that are placed outside the electric discharging space.

[0024]

As described above, by the use of the magnetic field lines (that have been used for plasma confinement) also for the plasma generation, high-density plasma can be generated efficiently at a low pressure, while increasing the uniformity of the plasma.

[0025]

[Mode for Carrying Out the Invention]

Referring now to the drawings, a description will be given in detail of preferred embodiments in accordance with the present invention.

[0026]

Fig. 1 is a vertical sectional view showing the construction of a surface processor in accordance with a first embodiment of the present invention. In Fig. 1, a reference number "1" denotes a vacuum container as the body of the surface processor. A discharging electrode 2 having a tube-like (e.g. cylindrical) shape is provided to the central part of the vacuum container 1. The discharging electrode 2 is insulated from lateral parts 1A and 1B (made of metal) of the vacuum container 1 by two ring-shaped insulators 3 on its both sides. The vacuum container 1 is built up as a hermetically sealed chamber by the tube-shaped discharging electrode 2 and the lateral parts 1A and 1B. The tube-shaped (e.g. cylindrical) part of the vacuum container 1 (excluding end face parts 1a and 1b) will hereafter

be called "peripheral face part". The interfaces between the discharging electrode 2 and the lateral parts 1A and 1B of the vacuum container 1 are vacuum-sealed by the ring-shaped insulators 3. When surface processing is carried out, the inside of the vacuum container 1 is maintained at a prescribed vacuum state (decompressed state) and necessary plasma is generated by letting introduced gas (gas for electric discharge) discharge electricity. Meanwhile, the lateral parts 1A and 1B are maintained at the ground potential.

[0027]

In the vacuum container 1, a plurality of (e.g. two) substrate holding mechanisms 5 are installed with their substrate holding surfaces facing one another. The substrate holding mechanisms 5 are mounted on the inner surfaces of the end face parts 1a and 1b on both ends of the vacuum container 1. Surface processing is carried out for substrates 6 (substrates to be processed) which are held by the two substrate holding mechanisms 5 respectively.

[0028]

A magnetic circuit 4 including ring-shaped permanent magnets is placed so as to surround the cylindrical peripheral face part of the vacuum container 1 including the discharging electrode 2. The magnetic circuit 4 includes a plurality of ring-shaped permanent magnets 401 and 402 which are arranged at proper intervals. The ring-shaped permanent magnets 401 and 402 are placed coaxially with the peripheral face part including the discharging electrode 2. At least two permanent magnets 401 are placed to surround the lateral parts 1A and 1B of the vacuum container 1, while at least two permanent magnets 402 are placed to surround the discharging electrode 2. Each

lateral part (1A, 1B) surrounds and contains a front space for the substrate 6 mounted on the substrate holding mechanism 5, and the ring-shaped permanent magnets 401 are placed to surround the front space. In the structure of the magnetic circuit 4 including the permanent magnets 401 and 402, the ring-shaped permanent magnets are magnetized radially so that magnetic poles of adjacent two permanent magnets will be opposite to each other as shown in Fig. 1.

[0029]

A surface of the substrate holding mechanism 5 on which the substrate 6 is mounted is placed nearby an end of the magnetic circuit 4 so as to be perpendicular to the central axis of the discharging electrode 2.

[0030]

The end face part 1a of the vacuum container 1 is provided with an evacuating mechanism 7, by which gas is eliminated from the inner space and the vacuum container 1 is evacuated. Meanwhile, a prescribed type of gas is introduced into the vacuum container 1 through a gas introducing mechanism (unshown) and a gas inlet pipe 8 at a preset amount of flow. By properly controlling the evacuating rate of the evacuating mechanism 7 and the introducing rate (flow) of the gas introducing mechanism, pressure inside the vacuum container 1 can be set and maintained properly.

[0031]

The discharging electrode 2 is supplied with necessary power from a power supply mechanism including an RF power supply 10 and a matching circuit 11. High-frequency electric power generated and adjusted by the RF power supply 10 and the matching circuit 11 is supplied to the discharging electrode 2 via a

feeder line 12.

[0032]

Incidentally, the above "power supply mechanism" can be defined more widely to include those supplying DC power, High-frequency (RF) power, microwave, etc. The following explanation will be given on an example in which the power supply mechanism supplies a high-frequency (RF) power of a particular frequency 13.56 MHz (designated as an "industrial frequency" in Japan).

[0033]

In the following, the basic operation of the surface processor composed as above will be described with reference to Figs. 1 and 2. Fig. 2 is a schematic diagram showing the statuses of the magnetic field and plasma generated by the effect of the magnetic field, in which the vacuum container 1 is drawn simplified and the insulators 3 and the substrate holding mechanisms 5 are not shown.

[0034]

First, the vacuum container 1 is evacuated by the evacuating mechanism 7 into a preset decompressed state and thereafter the prescribed gas is introduced into the vacuum container 1 through the gas introducing mechanism and the gas inlet pipe 6 up to a prescribed pressure. The prescribed pressure is determined optimally depending on the type of gas, magnetic field intensity, etc.

[0035]

Subsequently, the high-frequency electric power generated by the RF power supply 10 is supplied to the discharging electrode 2 via the matching circuit 11, by which electric discharge by the RF power occurs in the inner space

of the cylindrical discharging electrode 2 and thereby plasma is generated. The status of the generated plasma varies depending on the structure of the magnetic circuit 4.

[0036]

As shown in Figs. 1 and 2, the ring-shaped permanent magnets provided to the magnetic circuit 4 of this embodiment are separated into two groups having different effects (permanent magnets 401 and 402). The effect of the permanent magnets 401 is characterized in that their magnetic lines of force (hereafter, referred to as "magnetic field lines") 501 cross the walls of the lateral parts 1A and 1B of the vacuum container 1 only. Meanwhile, the effect of the permanent magnets 402 is characterized in that their magnetic field lines 502 cross the discharging electrode 2 and then spread in its inner space. Magnetic field lines 503 growing at the interfaces between the permanent magnets 401 and the permanent magnets 402 cross both the discharging electrode 2 and the walls of the lateral part 1A and 1B of the vacuum container 1.

[0037]

In the surface processing vacuum container 1 provided with the magnetic circuit 4 having the above effects, the plasma which is generated in the inner space of the vacuum container 1 by the discharging electrode 2 has the following characteristics.

In the case of supplying high-frequency electric power to the discharging electrode 2 in order to generate plasma, an electric field (an electric field as a mean value) due to the high-frequency voltage is allowed to be present on the surface of the electrode 2 so that electrons accelerated by the electric field collide with gaseous molecules (atoms) introduced into a vacuum container 1 so as to allow the molecules to be ionized,

thereby locally generating high density plasma that is diffused and maintained in the vacuum container 1. When the plasma is generated, the motion of the electrons in the plasma depends on magnetic field generated by a magnetic circuit.

In this embodiment, high density plasma 505 is generated especially at the points shown in Fig. 2 due to the interaction with the magnetic field 502. The plasma generation/maintenance mechanism employed in this embodiment is basically the same as that in conventional magnetron-type electric discharge reactors; however, to explain more specifically, the plasma generation/maintenance mechanism of this embodiment exhibits the following characteristics depending on the structure of the plasma-generating discharging electrode 2 and the ring-shaped permanent magnets 402 surrounding the discharging electrode 2.

[0038]

There is a voltage drop (a potential difference) between the inner surface of a cylindrical discharging electrode 2 and plasma generated in the inner space of the electrode 2, where a direct current electric field (an electrostatic field) is present. The direction of motion of electrons in the plasma depends on the electric field and the component of a magnetic field 502 orthogonal to the electric field wherein the magnetic field is generated by a permanent magnet 402. Specifically, the electrons move in the direction of the outer product of the electric field vector and the magnetic field vector (namely in the radially inward direction) and in the circumferential direction along the inner wall of the discharging electrode 2 under action of the electric field and the magnetic field wherein the movement path of the electrons is enclosed.

Due to the enclosed movement path of the electrons in the

plasma generation area, dissipation of the electrons in the plasma generation area is reduced, by which the high density plasma can be generated locally and maintained with ease.

The high density plasma generated by the construction of the present embodiment is characterized in that the plasma is formed in the ring-shaped area in the proximity of the inner surface of the discharging electrode 2 and generated in high density as indicated by reference number 505 illustrated in Fig. 2.

In order to generate the plasma in the ring-shaped area, it is necessary as mentioned above that a plurality of ring-shaped permanent magnets 402 be arranged around the cylindrical discharging electrode 2 so as to have the alternating magnetic pole arrangement and their magnetic field lines 502 intersect and cross the inner surface of the discharging electrode 2.

[0039]

In the plasma generated in the inner space of the discharging electrode 2 as described above, the ions and the activated gaseous molecules or atoms present in the plasma diffuse in the whole inner space of the vacuum container 1 so as to react with the thin film formed on the surface of the substrate 6 to be treated, thereby eliminating the film.

In this case, the magnetic field 501 generated by the permanent magnets 401 has the function of decreasing loss which is caused by collision of charged particles in the plasma with the inner surface of the lateral parts 1A and 1B of the vacuum container 1, maintaining high plasma density and improving the uniformity of plasma density in the vicinity of the surface of the substrate 6.

[0040]

In this embodiment, there is no need to install a discharging electrode inside the vacuum container 1 since the vacuum container 1 is built up as one piece by the lateral parts 1A and 1B and the discharging electrode 2. Further, since the magnetic circuit 4 in this embodiment can be placed in the atmosphere, a mechanism for cooling the magnetic circuit 4 can be installed and maintained easily.

[0041]

As is clear from the above embodiment, the surface processor according to the present invention is characterized in that it generates the high density plasma 505 in the ring-shaped area by use of the magnetic field 502 and then diffuses the ions and the activated gaseous molecules or atoms caused by the high density plasma 505 efficiently and uniformly by use of another magnetic field 501, thereby enabling the surface processing of the substrate 6.

[0042]

In the following, a second embodiment of the present invention will be described with reference to Fig. 3, in which the same reference characters as those of Fig. 1 designate substantially the same elements as those of Fig. 1. In the second embodiment, the discharging electrode is prepared separately from the vacuum container, and the cylindrical discharging electrode is placed inside the vacuum container 1 so as to be coaxial with the vacuum container and at the middle of the vacuum container in its axial direction. The reference number "2" in Fig. 3 denotes the cylindrical discharging electrode which is formed to have a smaller diameter than the vacuum container 1. While the discharging electrode 2 is

supported by some supporting members on the inner surface of the vacuum container 1, they are not shown in Fig. 3. High-frequency electric power is supplied to the discharging electrode 2 via a feeder line 12 which is drawn into the vacuum container 1 through a small pipe-shaped insulator 13 also serving as vacuum sealer, by which the plasma is generated. The gap 14 (clearance) between the vacuum container 1 and the discharging electrode 2 has to be set small enough so that no electric discharge will get therein. While appropriate gap width varies depending on the type and pressure of the discharging gas, a gap of several millimeters is desirable. Meanwhile, the vacuum container 1 is maintained at the ground potential.

[0043]

In this embodiment, the ring-shaped insulators 3 and the connecting structure between the discharging electrode 2 and the lateral parts 1A and 1B employed in the first embodiment become unnecessary, by which the construction of the apparatus is simplified. Further, since the discharging electrode 2 and the vacuum container 1 are manufactured as separate parts, a vacuum container 1 with the peripheral face part of a large diameter can be built up easily. The other apparatus composition and the magnetization directions of the permanent magnets 401 and 402 are exactly the same as those of the first embodiment. The plasma generation/maintenance mechanism employed in this embodiment is also the same as that explained in the first embodiment.

[0044]

In the above surface processors of the first and second embodiments, the inner surface of the vacuum container 1 is apt

to be sputtered by ions present in the plasma. Especially, a DC or AC bias applied to the substrate holding mechanisms 5 for carrying out the surface processing of the substrate 6 causes several problems, including the sputtering on the inner surface of the vacuum container 1, instability of electric discharge, etc. Such problems are caused in the above embodiments by the use of the vacuum container 1 (at the ground potential) as an electrode. In other words, the plasma potential changes according to the bias of the substrate holding mechanism 5 and thereby the potential difference between the plasma potential and the ground potential increases (that is, DC electric field in a sheath at the inner surface of the vacuum container 1 increases), by which sputtering due to ion acceleration is caused. Further, if the aforementioned potential difference becomes too high, the plasma might become unstable due to the occurrence of local arc discharge. The following embodiment is proposed in order to resolve such problems.

The structure of the magnetic circuit 4 is the same as in the case of the first and second embodiments.

[0045]

In the following, a third embodiment of the present invention will be described with reference to Fig. 4. The third embodiment is characterized in that a second cylindrical electrode 9 (hereafter, simply referred to as "cylindrical electrode 9") is provided between the discharging electrode 2 and the vacuum container 1 in the construction of the second embodiment. The cylindrical electrode 9, functioning as the anode, is formed to have a longer axial length than the discharging electrode 2. Preferably, the cylindrical electrode 9 is fixed on the vacuum container 1 via an insulator

(unshown) so that it will be floated electrically. It is also possible to provide a bias application mechanism including a bias power supply 19 to the cylindrical electrode 9 as necessary and apply a desired bias (including the ground potential) to the cylindrical electrode 9. Between the cylindrical electrode 9 and the vacuum container 1, a magnetic circuit 4 is installed. The construction of the magnetic circuit 4 is the same as that in the first and second embodiments.

[0046]

To the discharging electrode 2, high-frequency electric power is supplied via a feeder line 12 that is drawn through an insulator 13 on the vacuum container 1 (like the one in the second embodiment) and a similar small insulator 16 (also serving as vacuum sealer) on the cylindrical electrode 9, and plasma is generated by the high-frequency electric power. The insulator 16 can also be formed integrally with the insulator 13 by stretching the insulator 13. The plasma generation/maintenance mechanism employed in this embodiment is the same as those explained in the previous embodiments. The gap 15 between the discharging electrode 2 and the cylindrical electrode 9 is set small enough so that no electric discharge will get therein. The width of the gap 15 may be substantially the same as that of the aforementioned gap 14. Meanwhile, between the cylindrical electrode 9 and the vacuum container 1, a space enough for the installation of the magnetic circuit 4 is reserved. If the gap for the magnetic circuit 4 can not be secured between the vacuum container 1 and the cylindrical electrode 9, the magnetic circuit 4 can also be installed outside the vacuum container 1.

[0047]

According to the third embodiment, a cylindrical electrode 9 is electrically floated so that the potential of the cylindrical electrode 9 varies depending on the plasma potential even in the case of providing a direct current or alternating current bias to the substrate holding mechanisms 5, thereby the potential difference from the plasma potential is maintained small so as to resolve the malfunction in the second embodiment.

Further, even when the application of bias to the substrate holding mechanism 5 is difficult because of its structure, the energy of ions incident on the substrate 6 can be controlled properly by applying a bias to the cylindrical electrode 9. In high-frequency electric discharge, there are cases where the space potential of the plasma in the vicinity of the substrate 6 vibrates due to the high frequency discharge, by which the energy distribution of the ions incident on the substrate 6 might be widened and the micromachining process might be deteriorated. In such cases, instead of using the bias power supply 19 shown in Fig. 3, the cylindrical electrode 9 may be connected with the vacuum container 1 via a capacitor, by which high-frequency vibration relating to the potential of the cylindrical electrode 9 can be eliminated and the vibration of the plasma space potential can be suppressed. The capacitance of the capacitor may be set arbitrarily as long as it gives a sufficiently low impedance against the high-frequency electric power employed for the electric discharge.

[0048]

In the following, a fourth embodiment of the present invention will be described with reference to Fig. 5. In this embodiment, in the construction of the third embodiment, the

discharging electrode 2 includes large-diameter parts 201 having a larger diameter and small-diameter parts 202 having a smaller diameter which are repeated alternately and successively. Therefore, the discharging electrode 2 has a bellows-like shape in which the large-diameter parts 201 and the small-diameter part 202 are alternated in the axial direction. In the magnetic circuit 4, the permanent magnets 402 employed for generating plasma are placed in spaces that are formed between the cylindrical electrode 9 and the small-diameter parts 202 of the discharging electrode 2. The gap 17 between the cylindrical electrode 9 and the large-diameter part 201 of the discharging electrode 2 has to be set small enough so that no electric discharge will get therein. The width of the gap 17 may be substantially the same as that of the aforementioned gap 14. It is desirable that a similar gap be formed also between the cylindrical electrode 9 and the permanent magnets 402; however, the gap is not necessarily required when the permanent magnets 402 are formed of insulating material such as ferrite.

The other device constructions and the magnetizing direction of the permanent magnet are the same as in the case of the third embodiment.

[0049]

The plasma grows in the inner spaces of the large-diameter parts 201 of the discharging electrode 2. In the plasma generation in this embodiment, the high density plasma generation/maintenance mechanism by the magnetron electric discharge (explained in the first embodiment) and a plasma generation/maintenance mechanism employing the so-called "hollow cathode effect" (the generation of high density plasma

due to to-and-fro motions of electrons between closely placed cathodes) are combined, by which still higher plasma density is realized.

[0050]

In the following, a fifth embodiment of the present invention will be described with reference to Fig. 6. The fifth embodiment is characterized in the structure of the discharging electrode 2 and cylindrical permanent magnets 402 building up the magnetic circuit for plasma generation. In the discharging electrode 2 of this embodiment, a small-diameter part 203 (referred to as "inner electrode 203") with a smaller diameter and a large-diameter part 204 (referred to as "outer electrode 204") with a larger diameter, having the same axial lengths, are placed to overlap each other and electrically connected together. While the gap 18 between the outer electrode 204 and the discharging electrode 2 has to be set small enough to eliminate electric discharge therein in the previous embodiments, the gap 18 in this embodiment (to be used as a plasma generation space) is set relatively wider. While appropriate gap width varies depending on the pressure of the discharging gas, a gap of several centimeters is desirable.

[0051]

Further, two or more ring-shaped permanent magnets 403 for generating plasma are provided to the space between the inner electrode 203 and the outer electrode 204 of the discharging electrode 2. The magnetization directions of the ring-shaped permanent magnets 403 are set similarly to those of the permanent magnets 401. The positions of the permanent magnets 403 are set so that their outer magnetic poles will face the inner magnetic poles of corresponding permanent magnets 402 and each

facing pair of magnetic poles of the ring-shaped permanent magnets 402 and 403 will have the same polarity. The other apparatus composition and the magnetization directions of the permanent magnets 401 and 402 are exactly the same as those of the first embodiment.

[0052]

The cylindrical electrode 9 is held in the floating potential also in this embodiment, and the operating principle regarding the cylindrical electrode 9 is basically the same as that in the fourth embodiment.

[0053]

In this embodiment, the plasma is generated at two places: in the inner space of the inner electrode 203 of the discharging electrode 2 and in the gap 18 between the outer electrode 204 and the cylindrical electrode 9. The generating/maintaining mechanism for the plasma that is generated in the inner space of the inner electrode 203 is exactly the same as that explained in the first embodiment. Meanwhile, in the plasma generation in the gap 18, still higher plasma density is realized by virtue of the plasma generation/maintenance mechanism combining the magnetron electric discharge and the hollow cathode effect explained in the second embodiment.

[0054]

Incidentally, while the vacuum container in the above embodiments contained two substrate holding mechanisms placed at symmetrical positions, the present invention is also applicable to a vacuum container containing only one substrate holding mechanism.

[0055]

[Effects of the Invention]

As described above, by the present invention, in a surface processor employing magnetron electric discharge caused by high-frequency electric power etc., the structure of the discharging electrode is improved so that part of magnetic field lines that have been used in conventional surface processors for preventing the loss in plasma can also be used for the plasma generation by the magnetron electric discharge, by which high density plasma can be generated with efficiency and the uniformity of the surface processing of substrates can be maintained at a satisfactory level. The effects of the present invention become remarkable especially in the application to various plasma processors (dry etching apparatus, CVD apparatus, etc.) that are required high-speed and uniform wide-area processing.

While the present invention has been described with reference to the particular illustrative embodiments, it is not to be restricted by those embodiments but only by the appended claims. It is to be appreciated that those skilled in the art can change or modify the embodiments without departing from the scope and spirit of the present invention.

[Brief Description of Drawings]

[Fig. 1]

Fig. 1 is a vertical sectional view showing the construction of a surface processor in accordance with a first embodiment of the present invention.

[Fig. 2]

Fig. 2 is a schematic diagram showing essential part of the surface processor of Fig. 1.

[Fig. 3]

Fig. 3 is a vertical sectional view showing a surface processor in accordance with a second embodiment of the present invention.

[Fig. 4]

Fig. 4 is a vertical sectional view showing a surface processor in accordance with a third embodiment of the present invention.

[Fig. 5]

Fig. 5 is a vertical sectional view showing a surface processor in accordance with a fourth embodiment of the present invention.

[Fig. 6]

Fig. 6 is a vertical sectional view showing a surface processor in accordance with a fifth embodiment of the present invention.

[Fig. 7]

Fig. 7 is a cross-sectional view showing an example of a conventional parallel planer electric discharge reactor.

[Fig. 8]

Fig. 8 is a cross-sectional view showing an example of a conventional magnetron-type electric discharge reactor.

[Fig. 1]

MATCHING CIRCUIT 11

RF POWER SUPPLY 10

1: VACUUM CONTAINER

1A, 1B: VACUUM CONTAINER LATERAL PART

2: DISCHARGING ELECTRODE

3: INSULATOR

4: MAGNETIC CIRCUIT

5: SUBSTRATE HOLDING MECHANISM

6: SUBSTRATE

7: EVACUATING MECHANISM

8: GAS INLET PIPE

401, 402: RING-SHAPED PERMANENT MAGNET

501, 502, 503: MAGNETIC FIELD

[Fig. 2]

MATCHING CIRCUIT 11

RF POWER SUPPLY 10

[Fig. 3]

MATCHING CIRCUIT 11

RF POWER SUPPLY 10

[Fig. 4]

MATCHING CIRCUIT 11

RF POWER SUPPLY 10

[Fig. 5]

CYLINDRICAL ELECTRODE 9
VACUUM CONTAINER 1
SUBSTRATE HOLDING MECHANISM 5
MATCHING CIRCUIT 11
RF POWER SUPPLY 10

[Fig. 6]
MATCHING CIRCUIT 11
RF POWER SUPPLY 10

[Fig. 7] [PRIOR ART]
MATCHING CIRCUIT 78
RF POWER SUPPLY 77

[Fig. 8] [PRIOR ART]
MATCHING CIRCUIT 78
RF POWER SUPPLY 77